Supercritical steam generator

A **supercritical steam generator** is a type of boiler that operates at supercritical pressure, frequently used in the production of electric power.

In contrast to a subcritical boiler in which bubbles can form, a supercritical steam generator operates at pressures above the critical pressure – 3,200 psi or 22 MPa. Therefore, liquid water immediately becomes steam. Water passes below the critical point as it does work in a high pressure turbine and enters the generator's condenser, resulting in slightly less fuel use.

Technically, the term "boiler" should not be used for a supercritical pressure steam generator as no "boiling" actually occurs in the device.

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History of supercritical steam generation

Contemporary supercritical steam generators are sometimes referred to as Benson boilers.[1] In 1922, Mark Benson was granted a patent for a boiler designed to convert water into steam at high pressure.

Safety was the main concern behind Benson's concept. Earlier steam generators were designed for relatively low pressures of up to about 100 bar (10 MPa; 1,450 psi), corresponding to the state of the art in steam turbine development at the time. One of their distinguishing technical characteristics was the riveted water/steam separator drum. These drums were where the water filled tubes were terminated after having passed through the boiler furnace.

These header drums were intended to be partially filled with water and above the water there was a baffle filled space where the boiler's steam and water vapour collected. The entrained water droplets were collected by the baffles and returned to the water pan. The mostly-dry steam was piped out of the drum as the separated steam output of the boiler. These drums were often the source of boiler explosions, usually with catastrophic consequences.

However, this drum could be completely eliminated if the evaporation separation process was avoided altogether. This would happen if water entered the boiler at a pressure above the critical pressure (3,206 pounds per square inch, 22.10 MPa); was heated to a temperature above the critical temperature (706 °F, 374 °C) and then expanded (through a simple nozzle) to dry steam at some lower subcritical pressure. This could be obtained at a throttle valve located downstream of the evaporator section of the boiler.

As development of Benson technology continued, boiler design soon moved away from the original concept introduced by Mark Benson. In 1929, a test boiler that had been built in 1927 began operating in the thermal power plant at Gartenfeld in Berlin for the first time in subcritical mode with a fully open throttle valve. The second Benson boiler began operation in 1930 without a pressurizing valve at pressures between 40 and 180 bar (4 and 18 MPa; 580 and 2,611 psi) at the Berlin cable factory. This application represented the birth of the modern variable-pressure Benson boiler. After that development, the original patent was no longer used. The "Benson boiler" name, however, was retained.

1957: Unit 6 at the Philo Power Plant in Philo, Ohio was the first commercial supercritical steam-electric generating unit in the world,[2] and it could operate short-term at ultra-supercritical levels.[3] It took until 2012 for the first US coal plant designed to operate at ultra-supercritical temperatures to be opened, John W. Turk Jr. Coal Plant in Arkansas.[4]

Two current innovations have a good chance of winning acceptance in the competitive market for once-through steam generators:

- A new type of heat-recovery steam generator based on the Benson boiler, which has operated successfully at the Cottam combined-cycle power plant in the central part of England,
- The vertical tubing in the combustion chamber walls of coal-fired steam generators which combines the operating advantages of the Benson system with the design advantages of the drum-type boiler. Construction of a first reference plant, the Yaomeng power plant in China, commenced in 2001.

On 3 June 2014, the Australian government's research organization CSIRO announced that they had generated 'supercritical steam' at a pressure of 23.5 MPa (3,410 psi) and 570 °C (1,060 °F) in what it claims is a world record for solar thermal energy.[5]

Definitions

These definitions regarding steam generation were found in a report on coal production in China (https://www.americanprogress.org/issues/green/reports/2017/05/15/432141/everything-think-know-coal-china-wrong/) investigated by the Center for American Progress.

- Subcritical – up to 705 °F (374 °C) and 3,208 psi (221.2 bar) (the critical point of water)
- Supercritical – up to the 1,000–1,050 °F (538–566 °C); turbine speed increases dramatically, requires *advanced materials*
- Ultra-supercritical – up to 1,400 °F (760 °C) and pressure levels of 5,000 psi (340 bar) (additional innovations, not specified, would allow even more efficiency) India's first USC coal plant commissioned Sep 2019 runs at 600 °C and pressure of 270 kg/cm2 (264.8 bar) and 41.5% generation efficiency (https://www.powermag.com/india-starts-up-its-first-ever-usc-coal-unit/) or 3.3% more than existing conventional fleet.

Nuclear power plant steam typically enters turbines at subcritical values - for *Once Through Steam Generators* 153 bar and 330 C, lower temp but same pressure for U-Tube Steam Generators type.[6]

The term "advanced ultra-supercritical" (AUSC) or "700°C technology" is sometimes used to describe generators where the water is above 700 °C.[7]

The term High-Efficiency, Low-Emissions ("HELE") has been used by the coal industry to describe supercritical and ultra-supercritical coal generation.[8][9]

Industry leading (as of 2019) Mitsubishi Hitachi Power Systems charts its gas turbine combined cycle (https://www.mhps.com/products/gasturbines/) power generation efficiency (lower heating value) at well under 55% for turbine (steam) inlet temp of 1250 °C, roughly 56% for 1400 °C, about 58% for 1500 °C, and 64% for 1600 °C, all of which far exceed thresholds for AUSC or Ultra-supercritical technology.

See also

- Supercritical water reactor
- Boiler

Notes

1. "BENSON Boilers for Maximum Cost Effectiveness" (http://www.energy.siemens.com/hq/pool/hq/power-generation/power-plants/steam-power-plant-solutions/benson%20boiler/BENSON_Boilers_for_Maximum_Cost_Effectiveness.pdf) (PDF). *steam power plant solutions/benson boiler*. 2001. Retrieved 15 December 2016.
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3. "First U.S. Ultrasupercritical Power Plant in Operation" (http://www.powermag.com/first-u-s-ultrasupercritical-power-plant-in-operation/). *POWER Magazine*. 2013-02-01. Retrieved 2018-02-12.
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5. Jeffrey, Colin (June 3, 2014). "CSIRO sets world record in generating "supercritical" steam using solar power" (http://www.gizmag.com/solar-array-hottest-supercritical-steam-world-record/32371/). *gizmag.com*. Retrieved 2014-06-09.
6. http://www.thermopedia.com/content/1149/
7. Nicol, Kyle. "Status of advanced ultra-supercritical pulverised coal technology" (https://www.usea.org/sites/default/files/122013_Status%20of%20advanced%20ultra-supercritical%20pulverised%20coal%20technology_ccc229.pdf) (PDF).
8. *Submission to the inquiry into the retirement of coal fired power stations* (http://www.minerals.org.au/news/submission_to_the_inquiry_into_the_retirement_of_coal_fired_power_stations). Minerals Council of Australia. p. 12.
9. Wiatros-Motyka, Malgorzata. *An overview of HELE technology deployment in the coal power plant fleets of China, EU, Japan and USA*. IEA Clean Coal Centre. p. 9.

External links

- Thermopedia, "Benson boiler" (http://www.thermopedia.com/content/578)

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